LEVEL 12 NASTRAN EXPERIENCES
AT GENERAL DYNAMICS,
CONVAIR AEROSPACE DIVISION,
FORT WORTH OPERATION

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SUMMARY

The level 12 NASTRAN has been used to support the NASA/LaRC Advanced Transport Technology study, a predesign, short-response-time effort. Aeroelastic analyses were performed. NASTRAN calculated the vibration modes for the supported airfoil components and the entire unsupported vehicle. Other procedures were then used for the aeroelastic analysis, with procedure interfacing accomplished through use of the NASTRAN produced restart tape. Stiffness matrices were used in static aeroelastic analyses; natural vibration modes were used for flutter and flight control system definition. Various level 12 NASTRAN characteristics were discovered and are discussed; e.g., the ability to solve singular matrices in rigid format 1, run times using multipoint constraints, restart tape problems, and the inaccurate stresses from the quad membrane when used with anisotropic materials.

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INTRODUCTION

Two versions of NASTRAN have been acquired at the Convair Aerospace Division, Fort Worth operation, from COSMIC at the University of Georgia. Level 8.1.0 was implemented 5 May 1970 and was used until 12 March 1971, at which time the implementation of level 12.0.0 was finalized. Implementation was initially on an IBM 360/65/65/50 computing system. Current utilization is on an IBM 370-155 computing system.

To date, the most significant application of level 12 has been to perform an analysis for the natural modes of vibration of the baseline configuration of an Advanced Transport Technology (ATT) airplane. This was a predesign, short-response-time effort. The vibration modes were necessary for use in flutter analysis and as an aid in defining the flight control system. The stiffness matrices used in calculating the modes were also used for a static aeroelastic analysis.

The flutter and static aeroelastic analyses were performed in procedures foreign to NASTRAN. The interfacing between these procedures and NASTRAN was accomplished via the use of the NASTRAN-produced restart tape.

The following discussion centers around the NASTRAN ATT analysis. It is presented as Part I. However, validation of level 12 NASTRAN was being performed prior to, during, and following the ATT analysis. This revealed several NASTRAN characteristics, which are presented and discussed in Part II.

PART I

ATT SYMMETRIC VEHICLE NORMAL MODES

Prior to calculation of the normal modes for the symmetric vehicle, the stiffness matrices for the supported wing and tail components were calculated in NASTRAN and then used in a different procedure to perform static aeroelastic analyses. Vibration modes for the wing, tail and fin components were then calculated after the weights were defined. The idealization used for the wing is illustrated in Figure 1. Four frames have been used for the wing plots in order to better illustrate the details of the idealization and the grid sequencing.

The idealization for the horizontal tail is shown in Figure 2. The tail component stiffness matrix was calculated in a separate problem, but the grid-point numbers start at 301. This numbering sequence was used so that the same input data cards could be re-used in calculating modes for the unsupported vehicle.

The vehicle representation used to calculate symmetric vibration modes is illustrated in Figure 3. Advantage has been taken of the symmetry, and only one half the vehicle is represented. The wing and tail representations are the same as previously shown in Figures 1 and 2, respectively. As expected, the lines for these components are so numerous as to produce a smeared appearance. The fuselage, engine pylon, and nacelle were represented with a simple bar arrangement.

Multipoint constraints were used to tie the tail, wing, and fuselage together. Single-point constraints were applied along the vehicle plane of symmetry to suppress the antisymmetric modes. The SUPORT card was used to enhance the extraction of the zero frequency roots, and the Inverse Power Method was used to calculate the first seven flexible modes. The flexible modes are illustrated in Figure 4. The plot element (PLOTEL) was used to reduce the density of lines.

The problem used 331 grids, 956 degrees of freedom after fixing, 1193 elements (which include 89 lumped masses read in from CMASS 2 cards), 11 sets of multipoint constraints and 350 omitted coordinates. The CPU time was 41.3 minutes (69.9 minutes wall clock). Execution was on the IBM 360/65/65/50 computing system.

Four factors in the run time deserve mention. Modules MCE1 and MCE2, which perform the multipoint constraints required 3.3 minutes CPU time. This is considered excessive, and their use in the future will be avoided wherever possible. Module SMP1, which omits the coordinates, required 14.3 minutes CPU time. Module READ, which calculates the frequencies and modes, used 10.9 minutes. Module SDR1, which backfigures for the deflections omitted, used 2.1 minutes. The time required for calculation of the stiffness matrix was insignificant.

Because the omitted coordinates decrease the dynamic matrix size, the execution time could probably have been reduced by omitting more coordinates. This would extend the execution times for SMP1 and SDR1 but should be more than offset by the decreased time in READ. In fact, had the dynamic matrix been reduced to the same size as the number of lumped masses (i.e., 89), then the transformation method would probably have calculated all the frequencies in less time than that required for the Inverse Power Method to calculate seven.

PART II

SOME LEVEL 12 CHARACTERISTICS

The decision to use NASTRAN for the ATT analysis was made primarily on the basis of the experiences with level 8 (see Reference 1). Since level 12 had been implemented for use at this time, it was quickly explored with some small inexpensive sample problems to validate that it could satisfactorily handle the task. The results were positive, but some characteristics of interest were discovered. These characteristics, together with those which became apparent during and following the ATT analysis, are presented.

Checkout Preliminary to the ATT Analysis

Use of the Inverse Power Method

The first check problem run was a simple unsupported-beam vibration problem. The beam frequencies were known in advance, the first being 3.5 Hz. Because the Inverse Power Method would be used for the ATT, it was stipulated for use in the check problem, and a tight frequency band (3.4 to 3.7 Hz) was defined on the EIGR card. To economize on computing time, two modes were requested (to insure that multiple roots could be extracted). However, only one mode was calculated because the procedure shifted four times (maximum number allowed in the algorithm) while tracking the root that was correctly calculated. Two items contributed to the large number of shifts: (1) The decomposition time estimate used in NASTRAN is less than the actual time used. (2) The user-stipulated frequency band was too small. This caused the starting point to be positioned close to the root and the shifted eigenvalues, calculated during iteration, to be small. The small numerical values obtained for the shifted eigenvalues made it difficult for the algorithm to sense convergence. Also, the tight frequency band restricted the amount of shift.

The stipulated frequency band was then changed to 3.4 to 6.0 Hz and a restart made. One root was estimated to lie within the band; two roots were requested. This time three roots were obtained, two of which were rigid-body or zero-frequency roots. The correct flexible root was first obtained, and the two rigid-body roots were next obtained by iteration. According to the documentation (Reference 2), the procedure should have moved outside the stipulated band during the search procedure, but should have searched down to approximately 3.2 and up to approximately 6.1 Hz. Hence, moving all the way down to the zero-frequency level was a surprise and is undesirable because not only is it too far outside the stipulated band, but to extract repeated roots by a root-tracking method is computationally expensive.

Use of the SUPORT Card

Because of these results, it was determined that the SUPORT card should always be used when calculating modes for unsupported structures, even though the frequency band stipulated on the EIGR card may be well removed from the zero-frequency position. Use of this card allows the extraction of zero-frequency roots by a direct method (i.e., without iteration), which saves on computer time, and then reverts to iteration for extraction of the flexible modes. The disadvantage is that a price (however small) is paid for the roots even though they may not be desired for use.

A subsequent restart, using this type card, validated that it yielded satisfactory results and does prohibit the iteration for the repeated (zero-frequency) roots.

Backfiguring for Deflections

In performing the modal analysis on the simple beam, the OMIT card was used to eliminate several coordinates that did not have lumped masses attached. The deflections for these eliminated coordinates form a subset of the deflections in the eigenvector and were not needed for subsequent analysis. In NASTRAN, the eigenvectors for those remaining coordinates (the active set) are first calculated and then a backfiguring operation is used to calculate the deflections for those eliminated. Since the user has the option of requesting deflections for either the "deflection" set or the "solution" set, it was reasoned that requesting the "solution" set would save the computer time used in backfiguring. (The "solution" set means those coordinates used in the solution, e.g., modal coordinates, grid points and extra points, etc.) This was done with the result that no eigenvectors were printed. Hence, it is necessary to pay the price for the backfiguring computations, even though the deflections for the eliminated coordinates may not be desired.

It was later determined that the module which performs the backfiguring operation, i.e., SDR1, used only 129 seconds of CPU time during the ATT modal analysis. This is relatively inexpensive.

Failure to Punch Modes

Initially, it was desired to cause NASTRAN to punch the calculated modes of vibration in card deck form. It was planned that these would be used as input data to other digital procedures that use the NASTRAN results in calculating static and dynamic aeroelastic response. However, a check problem revealed that NASTRAN will not currently punch modes. Because of this, and because the format of the punchout was unknown, it was decided to code a small procedure that would read the NASTRAN-produced magnetic tape, normally used for restarts, and extract the desired information.

The small coding task was accomplished by a programmer in 4 hours. The result was a procedure that acted as a front step to the aeroelastic and flutter procedures and successfully used the NASTRAN restart tape to bridge the interface between them and NASTRAN.

Calculation of Masses External to NASTRAN

When using NASTRAN to calculate natural vibration modes, dynamic response, or "pseudo" static inertia relief, the easiest and most convenient approach is to allow NASTRAN to calculate its own mass matrix. Even though this approach had been operationally validated, the calculation of the mass matrix outside of the finite-element procedure in which it is to be used is sometimes desirable. It becomes desirable when (1) the design process makes the flight vehicle weight data available in a form more suited to manual lumping of masses, and/or (2) it is necessary to match the static unbalance and pitch inertia of an airfoil structure while simulating only the "box" part or, at least, excluding the most forward part of the leading edge and the most aft portion of the trailing edge. Such was the case with the ATT study.

The most convenient means of supplying mass information to NASTRAN for the ATT was through the use of the CMASS type card; specifically CMASS2 was used. This type card was selected because the mass definition and grid connection were defined on a single card. Hence, this type approach was validated with a sample problem.

The sample problem indicated that modes are satisfactorily calculated when manually lumped masses are used. Unfortunately, it also revealed that the vehicle weight and balance information (normally available under option) is not printed upon request when the masses are calculated externally to NASTRAN.

Evaluation During the ATT Analysis

Solution of Singular Matrices

NASTRAN was used to generate the stiffness matrix for each of the three ATT supported airfoil structure components (i.e., wing, tail, and fin) prior to a static aeroelastic analysis. The matrices were generated by Rigid Format 1, and a single mechanical load was applied (for checking) to the structure for which deflections and reactions were calculated. The deflections and reactions obtained served to increase the level of confidence in the validity of the stiffness matrices.

In checking one component, supports were not applied in one direction (inadvertently), which allowed a rigid-body degree of freedom to exist within the horizontal plane of motion. The mechanical load condition used for validation was a force-applied normal to this horizontal plane. The inclusion of this rigid-body degree of freedom means that the stiffness matrix is singular (i.e., its determinant is zero). Algorithms designed for static analysis conventionally will not successfully solve this type of matrix. However, NASTRAN used the singular matrix and obtained correct answers. This was a pleasant surprise.

According to Reference 3, Section 3.2, a singularity check is performed on the stiffness matrix. This check is performed by module GPSP (DMAP statement 61, Rigid Format 1). However, the check simply determines if any coordinates which do not have a finite value of stiffness assigned remain in the matrix after application of single and multipoint constraints. When all coordinates possess finite-stiffness values, module GPSP assumes the matrix to be nonsingular. Hence, a matrix which is singular because at least two rows are linearly dependent (i.e., a rigid-body mode is contained) is successfully passed through GPSP.

Module RBMG2 is then used to decompose the symmetric real matrix into upper and lower triangular form. As a result of this decomposition, the upper triangular matrix will have a zero term in the last diagonal position when the original matrix is singular. (When the original matrix is 2 times singular, the last 2 diagonals will be zero, etc.)

Deflections under load are then calculated in module SSG3 through use of the decomposed matrix and the user-supplied loads. The deflections are calculated by performing forward-backward substitution. In performing the backward pass, the calculation for the nth deflection becomes $U_n = 0/0$, which is indeterminant. The numerator is zero because all loads are zero in the direction of the rigid-body deflection. The denominator is zero because the matrix is singular.

It is believed that because of roundoff errors, the denominator used in NASTRAN was not exactly zero. The numerator was exactly zero because loads were user-supplied. Hence, the result would be a determinant situation, i.e., zero deflection.

Upon completion of the ATT analysis, a small check problem was run which accurately recreated the above situation while greatly simplifying the picture. The static analysis was correct and did use a singular matrix.

Use of Multipoint Constraints

What has historically been termed "beaming" at Convair Aerospace is termed "Multipoint Constraints" (or MPC) in NASTRAN. However, the computational expense for MPC's in NASTRAN is considered by this writer to be excessive. The symmetric ATT airplane modal analysis used 10 sets of MPC's which were summed in an eleventh set. Each set involved only two degrees of freedom. The modules timed, MCE1 and MCE2, required 200 CPU seconds for execution.

Restart Tape Problem

Two restart failures have occurred. One failure occurred during the ATT analysis, which cost a significant amount of execution time. The second failure occurred on a small check problem following the ATT analysis. The failures were of the same type and the critique printed was "System Fatal Message 36, Cannot Find File Named XVPS on Old Problem Tape." XVPS is a variable-parameter-set table printed on the restart tape during each CHKPNT operation.

The solution used for this latest restart failure was to remove from the checkpoint dictionary the cards punched from the last CHKPNT operation. This forfeited one milestone, but the subsequent restart was successful. Forfeiting one milestone was not significant since the solution of a problem will involve from 24 to 36 milestones, depending on the rigid format being used.

Post ATT Analysis - Additional Evaluation

Following the analysis of the ATT, two additional areas were explored with small problems.

Normal Modes by Transformation

One of the extensions made in level 12.0.0 was the addition of a transformation method to calculate vibration modes. Because this method had not been previously used, a small test problem was solved with it. The problem consisted of a flat anisotropic plate, cantilevered along one edge. Test modes and frequencies were available for comparison.

The idealization used is shown in Figure 5. Deflections were fixed to zero value at grids 1 through 6. Twenty-five quadrilateral bending plate (QDPLT) elements were used. Ninety degrees of freedom existed after fixing; sixty of these were omitted, leaving a dynamic matrix of size 30.

All 30 frequencies were extracted, and the first 12 modes were printed and plotted. Computer time required was 4.0 CPU minutes. It is interesting to note that this problem had previously been run, where the Inverse Power Method was used to calculate only the first 4 modes. However, the CPU time was 4.4 minutes.

Only the first seven modes and frequencies are available from test. The calculated/test frequency comparison is shown in Table 1. Testing was accomplished by both acoustic and holographic methods; hence, both results are shown. Note that the NASTRAN/test comparison is better than the test/test comparison. No "tuning" was performed in the analysis. Considering the crudeness of the model, this is considered excellent.

The first seven vibration modes are shown in Figure 6. Test modes were not available for inclusion in this report; however, the modes and node lines compare very well, as would be expected from the frequency comparison.

Static Analysis of Anisotropic Membrane

This problem had previously been solved to validate level 8, wherein it was discovered that the quadrilateral membrane element produced inaccurate stresses when used with anisotropic type materials (correct stresses were calculated for isotropic materials). The analysis subject was an anisotropic membrane of rectangular shape. Stresses were correctly calculated when the triangular membrane was used.

Hence, this problem was again used to verify that the correction for the quadrilateral element had been made to level 11.1 and above (as was indicated in Soft-ware Problem Report Number 21).

The results showed that the quadrilateral element is still defective. (This was reported to NASA and logged as SPR 446.) Hence, the switch was again made to the triangular element to validate its accuracy in level 12.0.0. The results were accurate. Also, solutions were obtained in one computer pass to the multiple loads with different boundary conditions.

CONCLUSIONS

NASTRAN continues to be the most versatile of any individual procedure. It has been successfully used to support the ATT study, a predesign, short-response-time effort. However, its execution costs are not yet competitive with its contemporaries.

Some of its operating characteristics are as follows:

1. When using the Inverse Power Method for calculating natural modes of vibration, computer time can be saved if the starting point(s) for iteration is spaced a reasonable distance away from the root(s) to be extracted (rather than too close). This is accomplished by stipulating a reasonably wide band in the input data.

2. When calculating natural modes of vibration for unsupported structures, the SUPORT card should always be used. This causes the rigid-body modes to be calculated by a direct method, whether or not the modes are desired for use. If the SUPORT card is not used, there is the danger that the repeated zero-frequency roots may be calculated by iteration, which is an expensive process. This can occur even though these roots may lie well outside the user-stipulated frequency band.

3. Backfiguring of deflections for those coordinates eliminated through use of the OMIT card cannot be avoided by requesting that displacements be printed for the solution set. The eliminated coordinates form a subset of the displacements for each eigenvector.

4. Vibration modes (eigenvectors) cannot be punched on cards at present in level 12.0.0 because of a programming error.

5. NASTRAN will solve singular matrices in performing static analysis when the matrix singularity is due to its containing a rigid-body degree of freedom and when no mechanical load component is aligned with the rigid-body degree of freedom.

6. System Fatal Message 36 occurred twice during restart and the run was aborted. A successful restart was accomplished by removing from the checkpoint dictionary those cards punched during the latest checkpoint operation. This sacrificed the most recent milestone traversed.

7. The use of Multipoint Constraints should be avoided in NASTRAN whenever possible because it is computationally expensive.

REFERENCES

1. Allen, M. G., "NASTRAN Experiences of Fort Worth Operations, Convair Aerospace Division of General Dynamics", paper presented at Colloquium at Langley Research Center, September 13-15, 1971 and published in NASA TM X-2378, NASTRAN: User's Experiences, September 1971.

2. MacNeal, R. H. (Editor), The NASTRAN Theoretical Manual, NASA SP-221, September 1970.

3. McCormick, C. W. (Editor), The NASTRAN User's Manual, NASA SP-222, September 1970.

Table 1 Anisotropic Cantilevered Plate Calculated/ Test Frequency Comparison

Mode Order	Frequencies in Hz			Percent Error	
	Holographic Test	NASTRAN	Acoustic Test	NASTRAN / Holographic	NASTRAN / Acoustic
1	24.0	24.6	25.1	+2.5	-2.0
2	81.0	78.8	83.6	-2.7	-5.7
3	145	150	155	+3.4	-3.2
4	196	200	203	+2.0	-1.5
5	316	327	331	+3.5	-1.2
6	352	384	369	+9.1	+4.1
7		455	469		-3.0

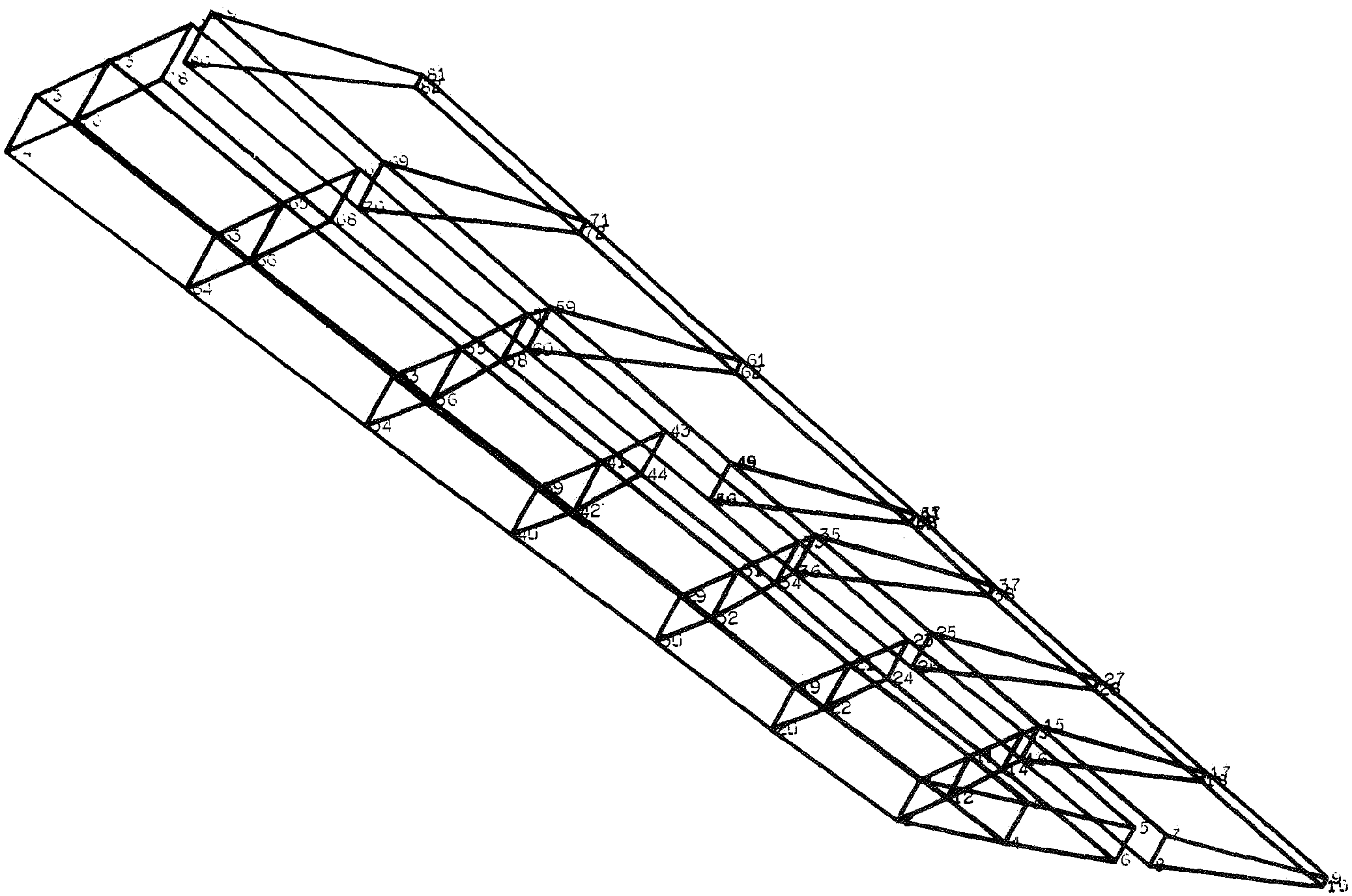


Figure 1.- ATT wing idealization (outboard section), frame 1 of 4 frames.

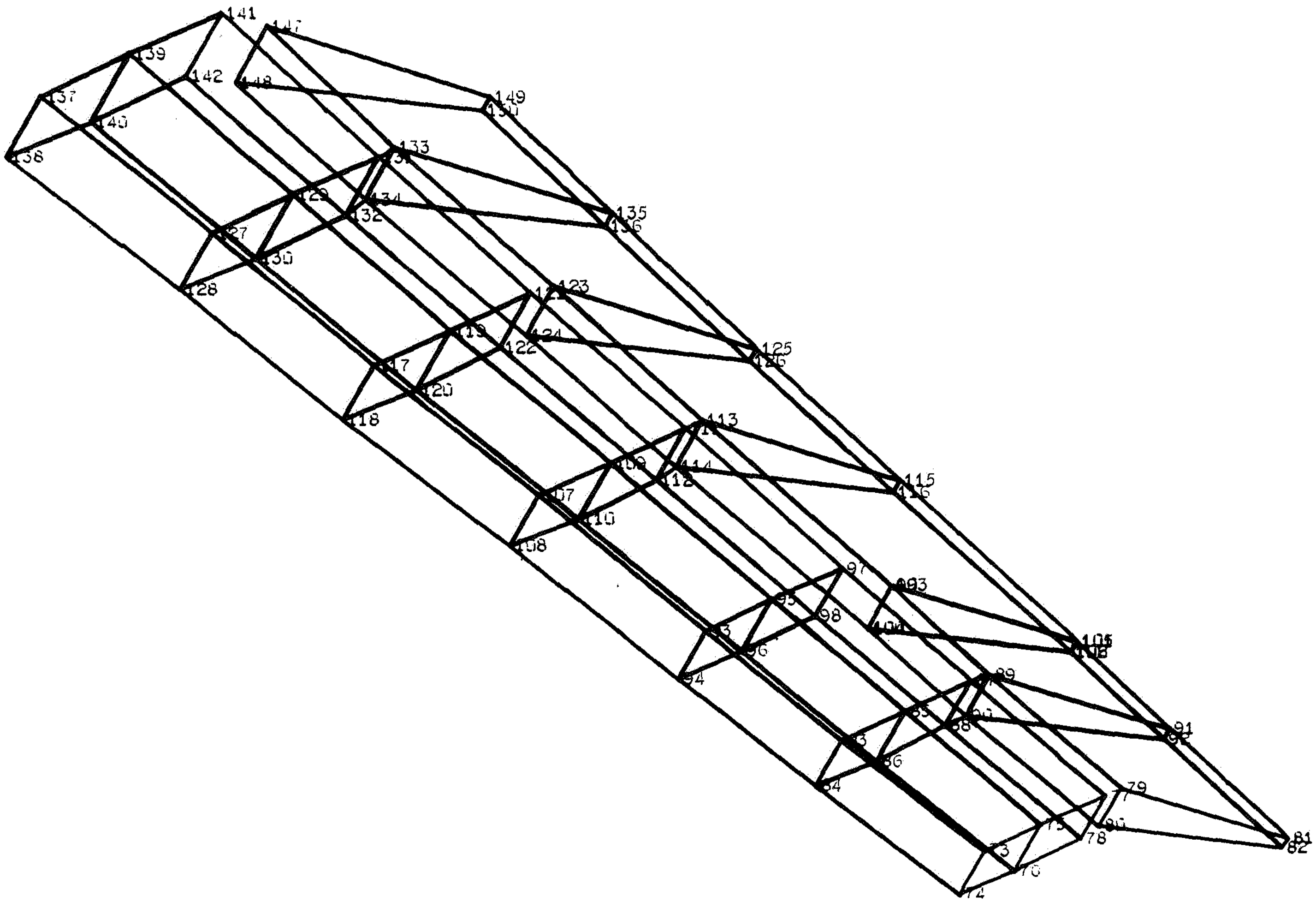


Figure 1.- ATT wing idealization (mid section), frame 2 of 4 frames - Continued.

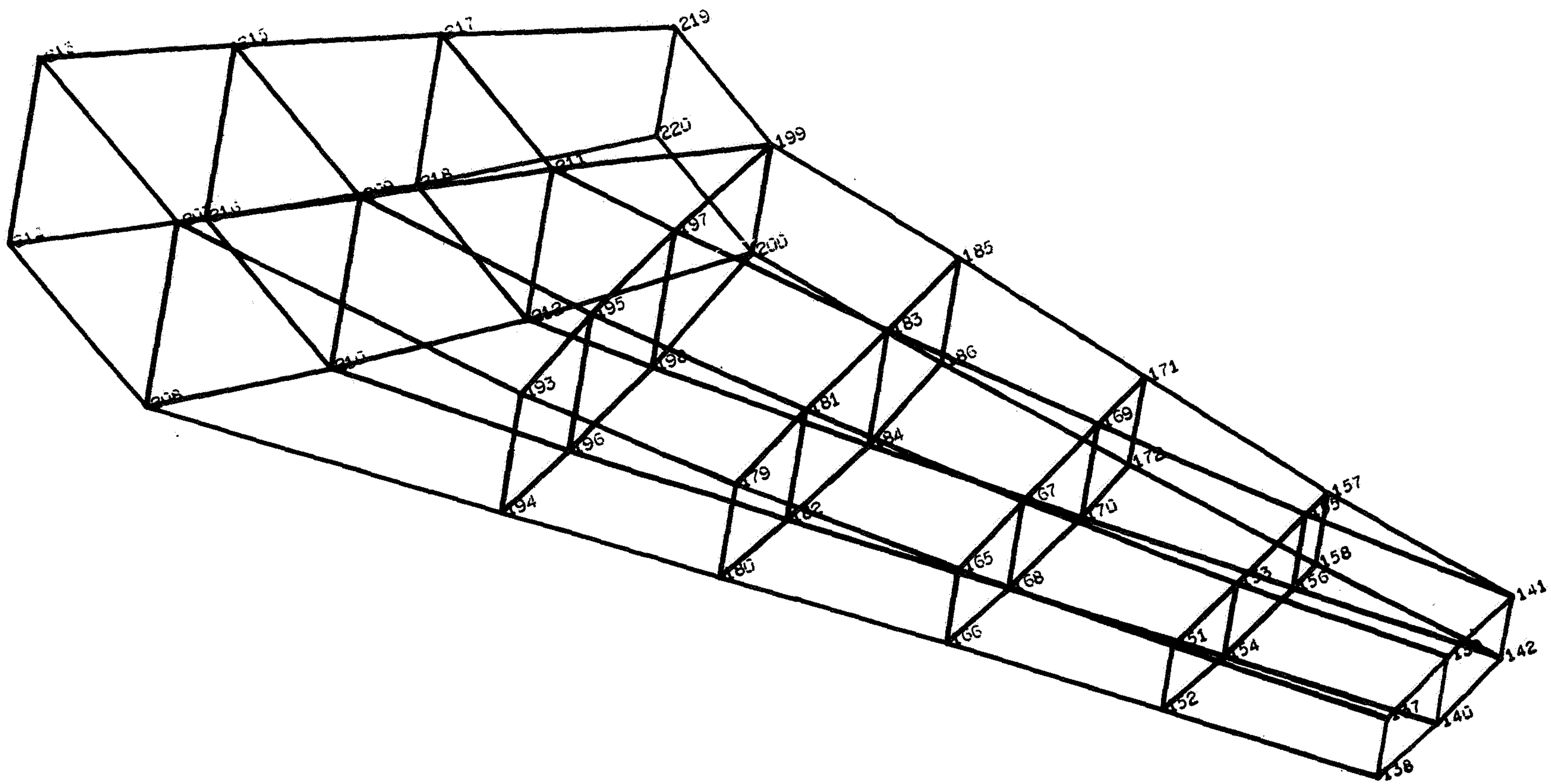


Figure 1.- ATT wing idealization (inboard-forward section), frame 3 of 4 frames - Continued.

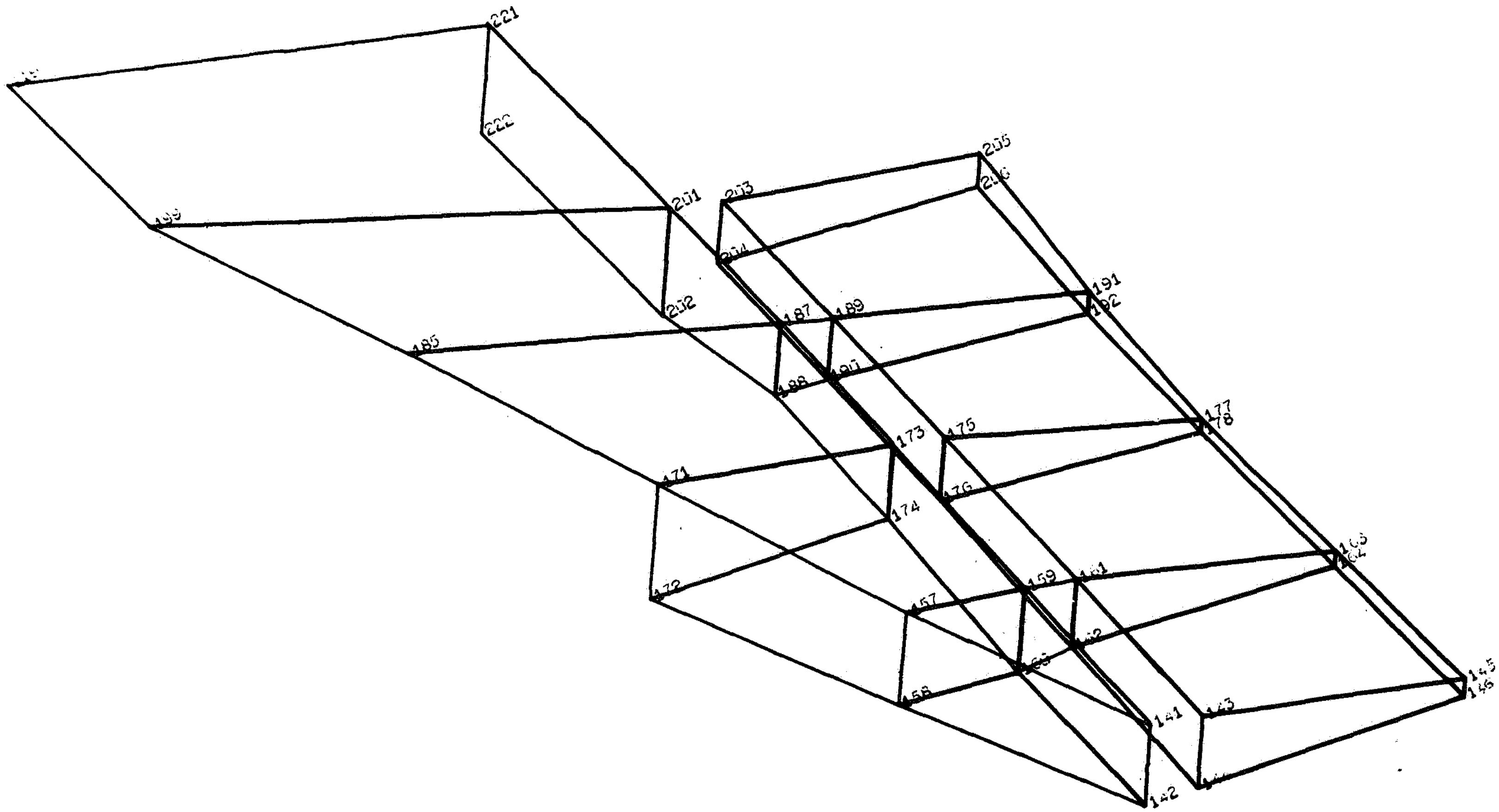


Figure 1.- ATT wing idealization (inboard-aft section), frame 4 of 4 frames - Concluded.

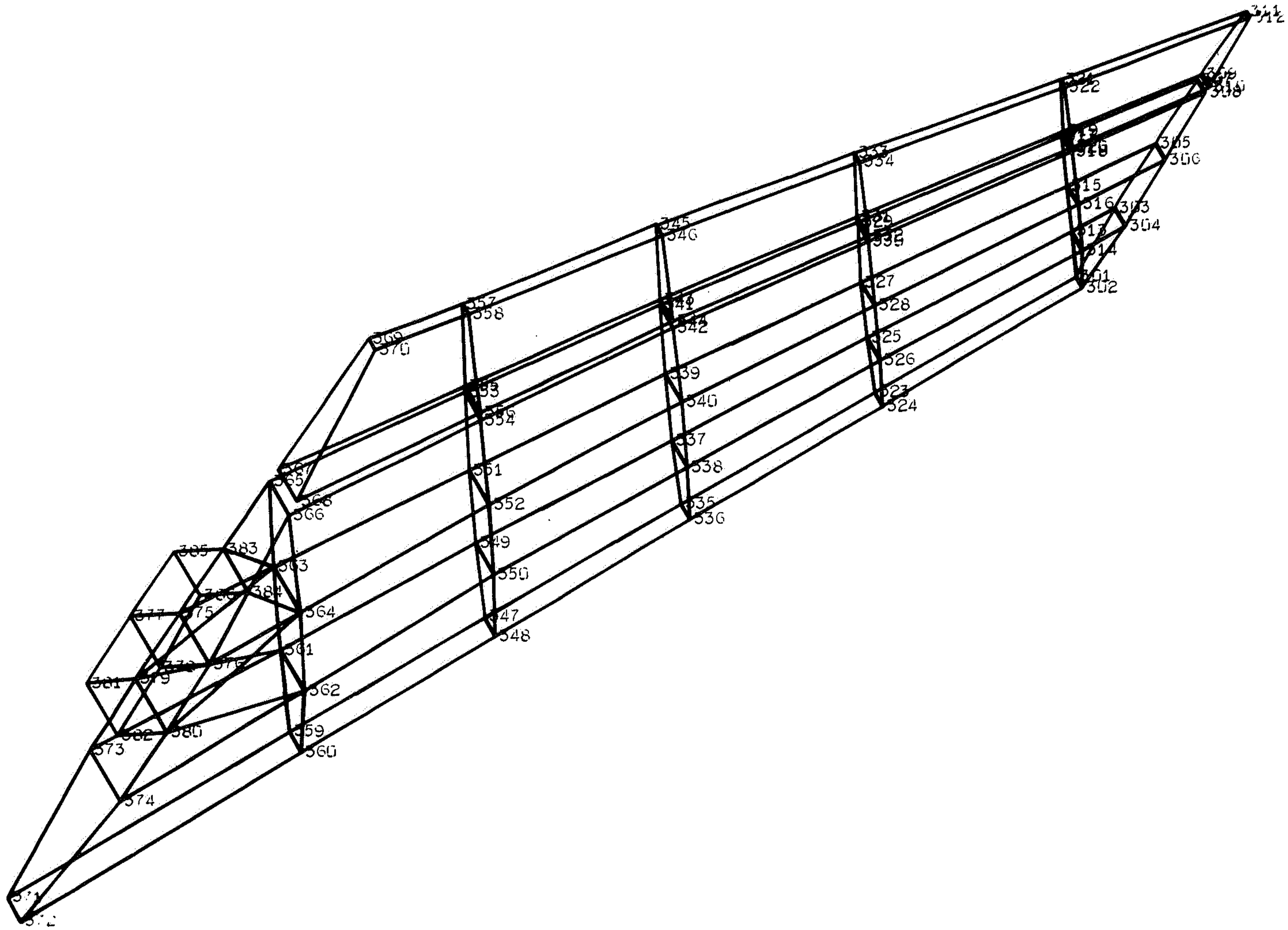


Figure 2.- ATT tail idealization.

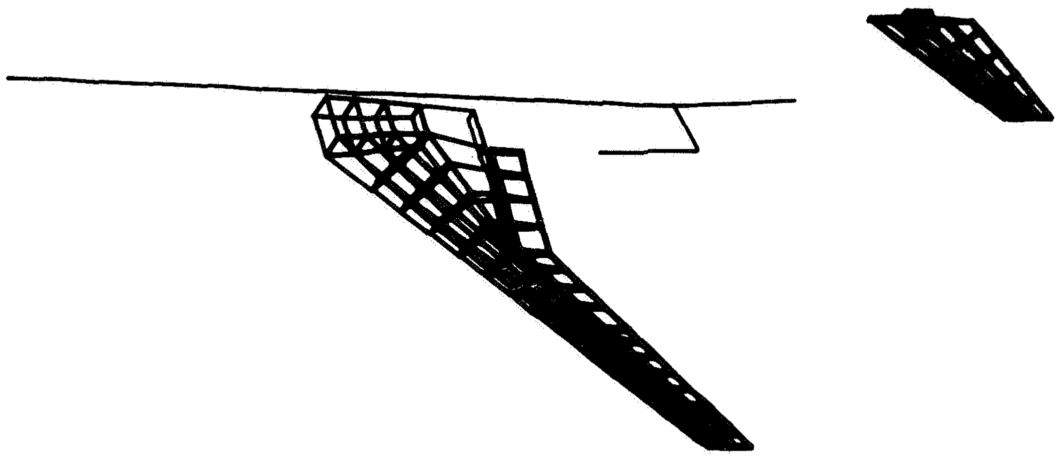
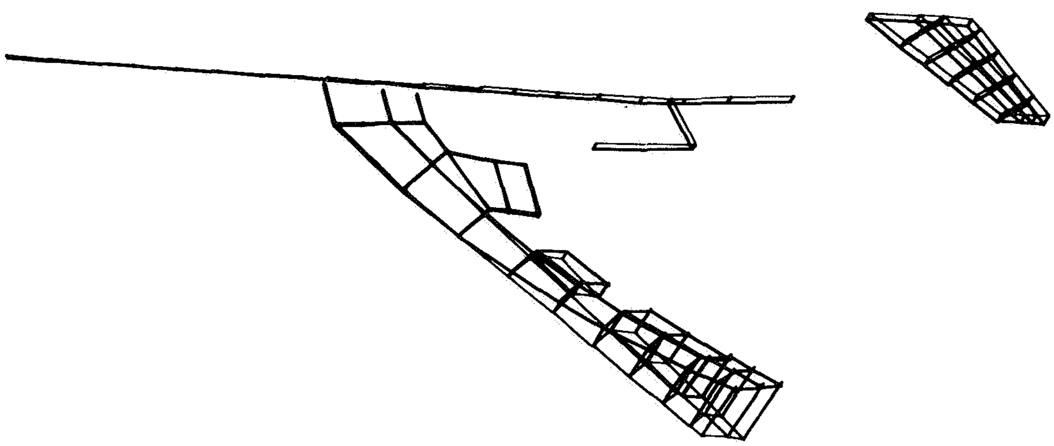
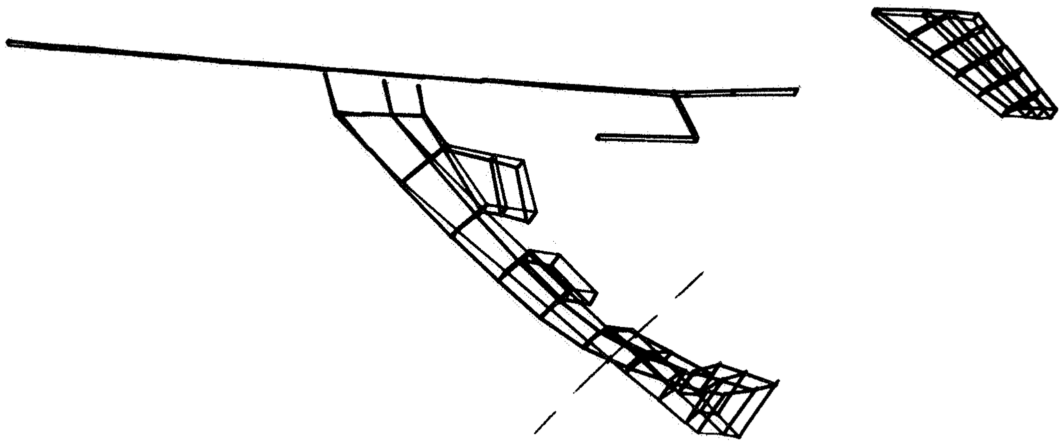


Figure 3.- ATT symmetric vehicle representation.

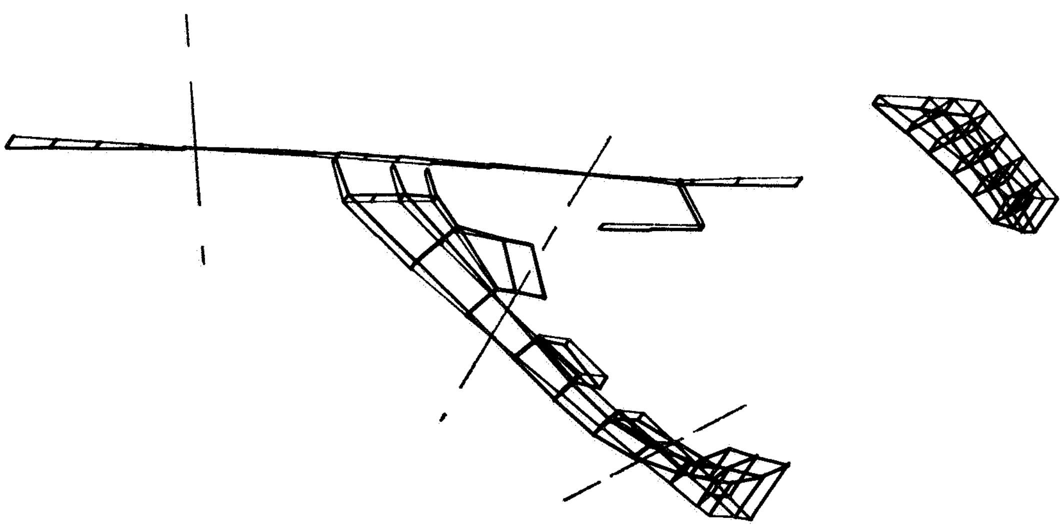


Mode 1, $f_1 = 0.95$ Hz

Figure 4.- ATT symmetric vehicle modes.

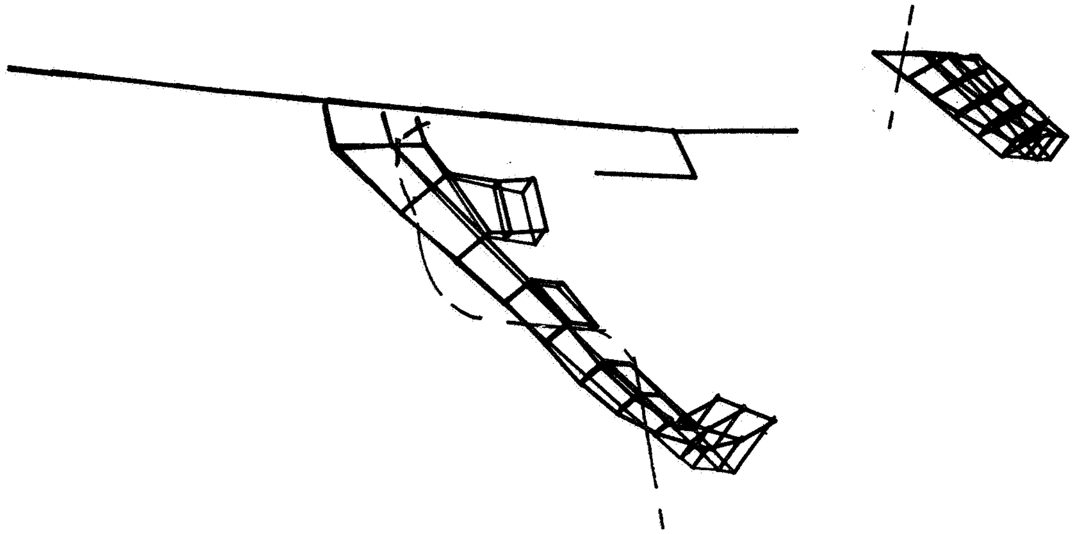


Mode 2; $f_2 = 2.45$ Hz

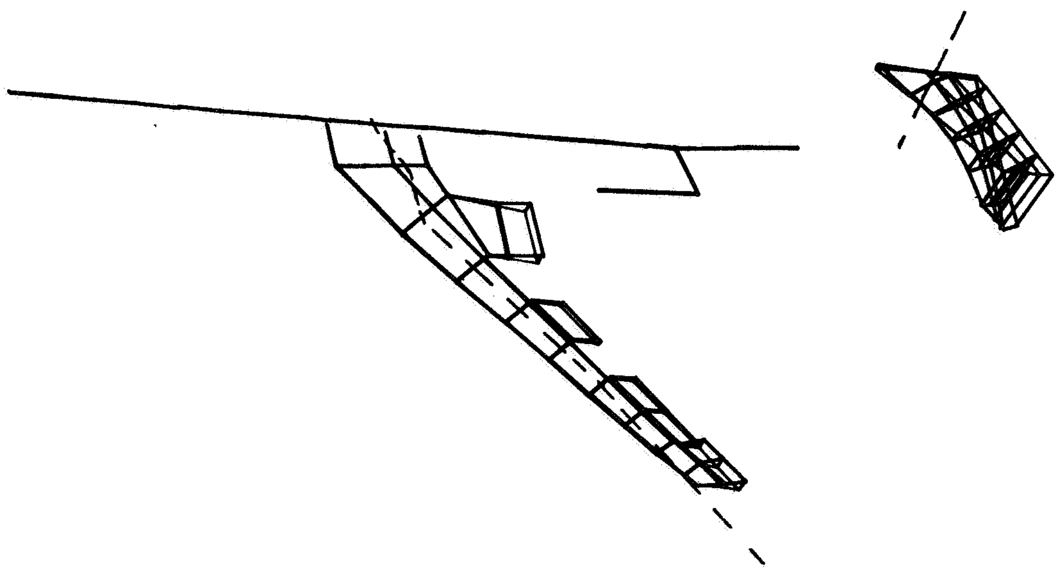


Mode 3; $f_3 = 3.73$ Hz

Figure 4.- ATT symmetric vehicle modes - Continued.

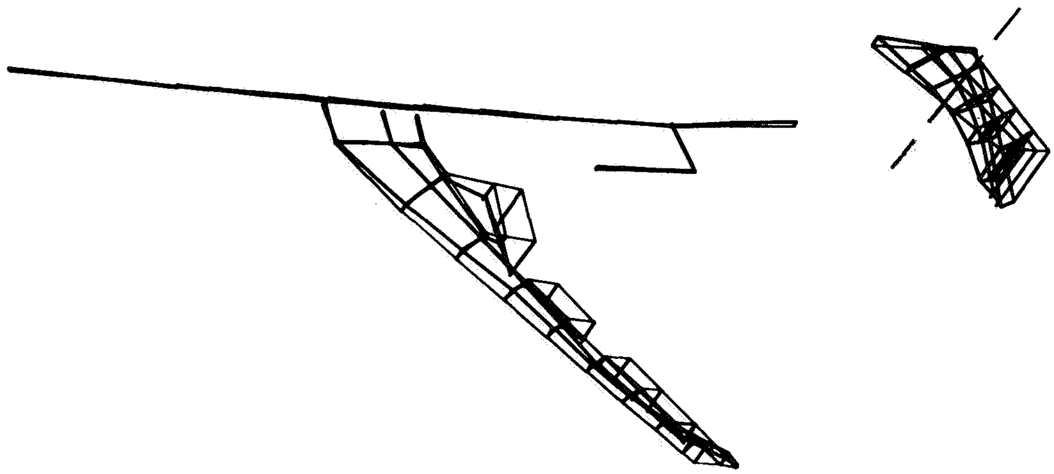


Mode 4; f_4 = 5.30 Hz

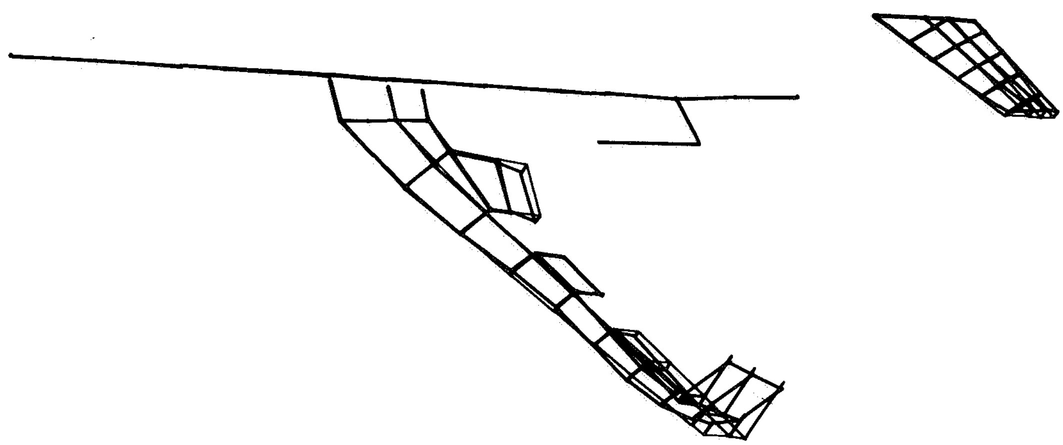


Mode 5; f_5 = 5.91 Hz

Figure 4.- ATT symmetric vehicle modes - Continued.

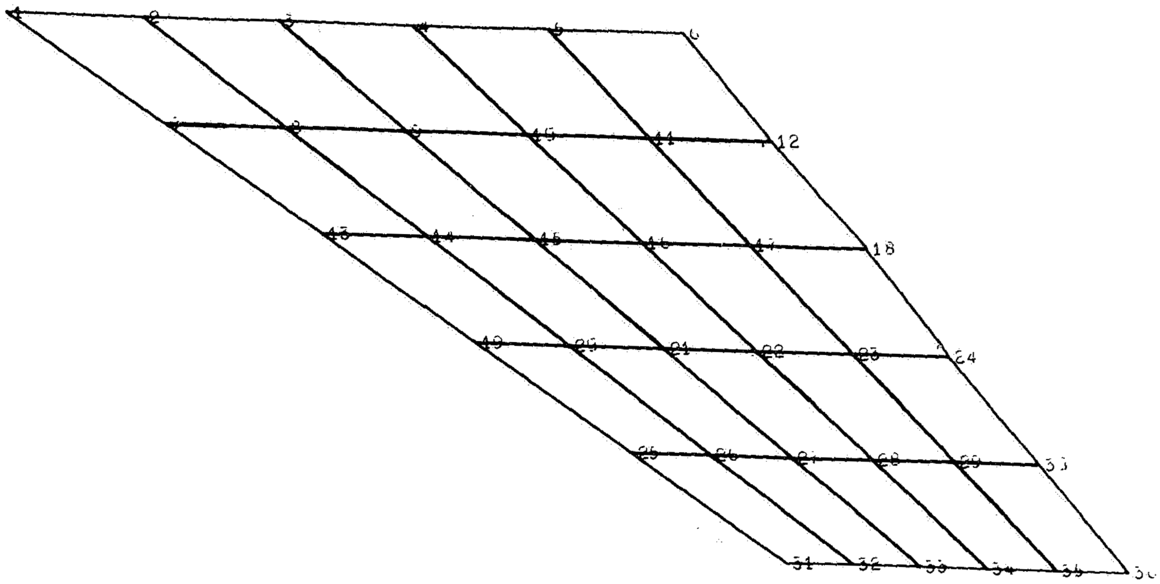


Mode 6; $f_6 = 6.53$ Hz

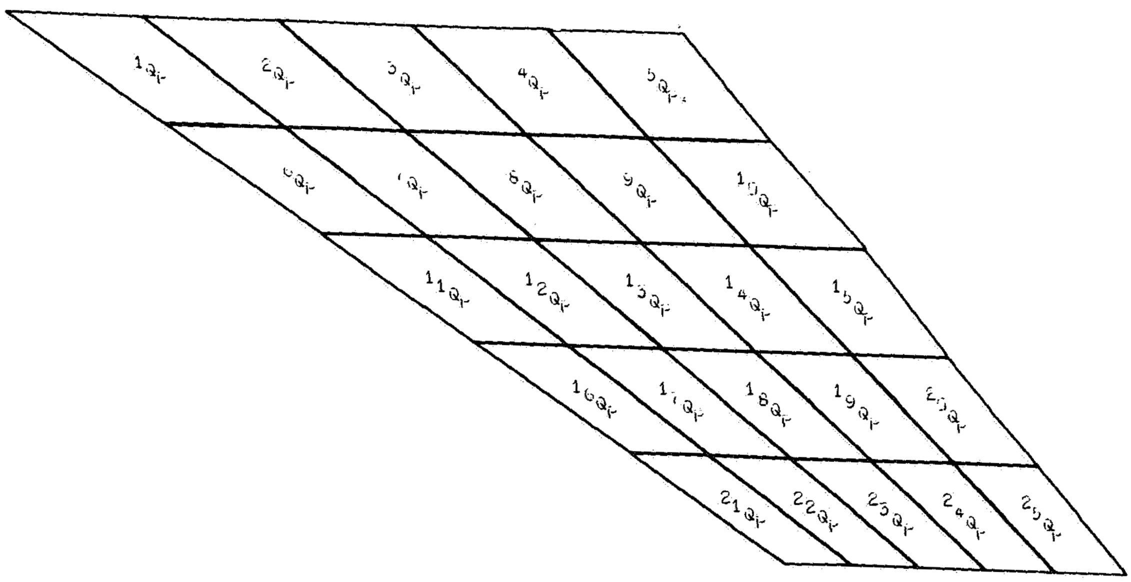


Mode 7; $f_7 = 7.57$ Hz

Figure 4.- ATT symmetric vehicle modes - Concluded.

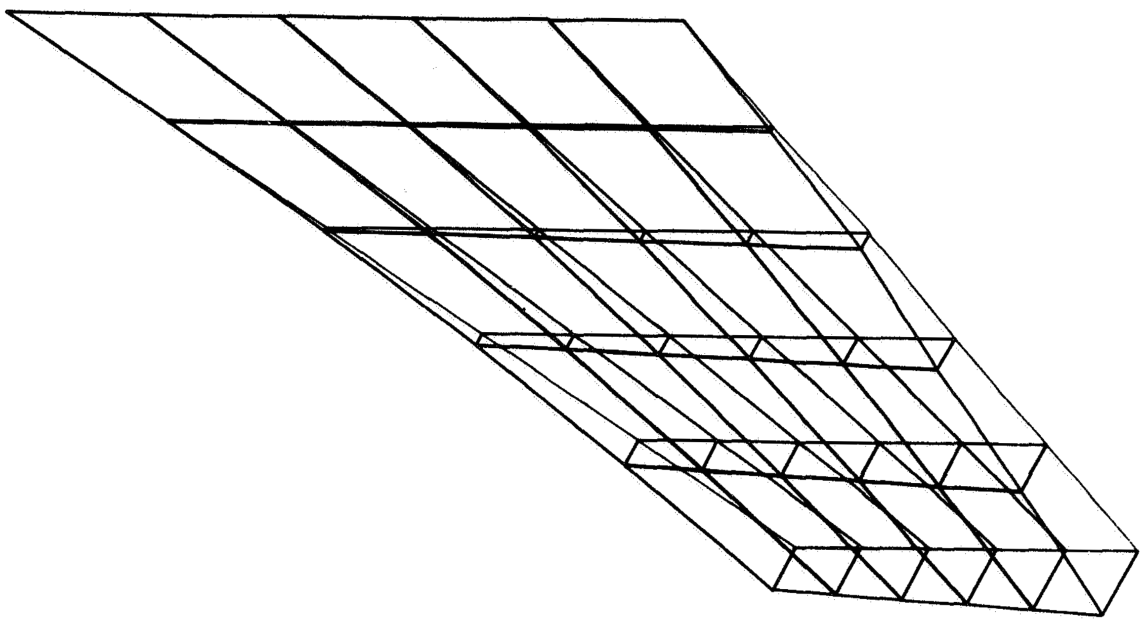


Grid-Point Locations

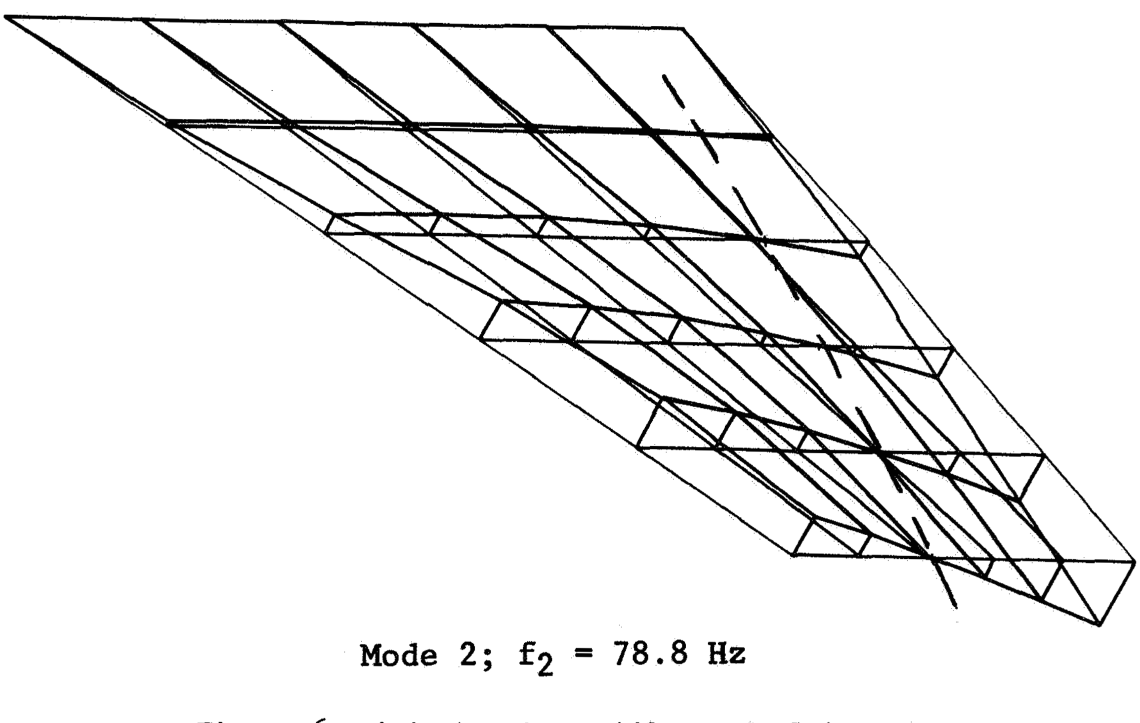


Finite-Element Locations

Figure 5.- Idealization of anisotropic plate.

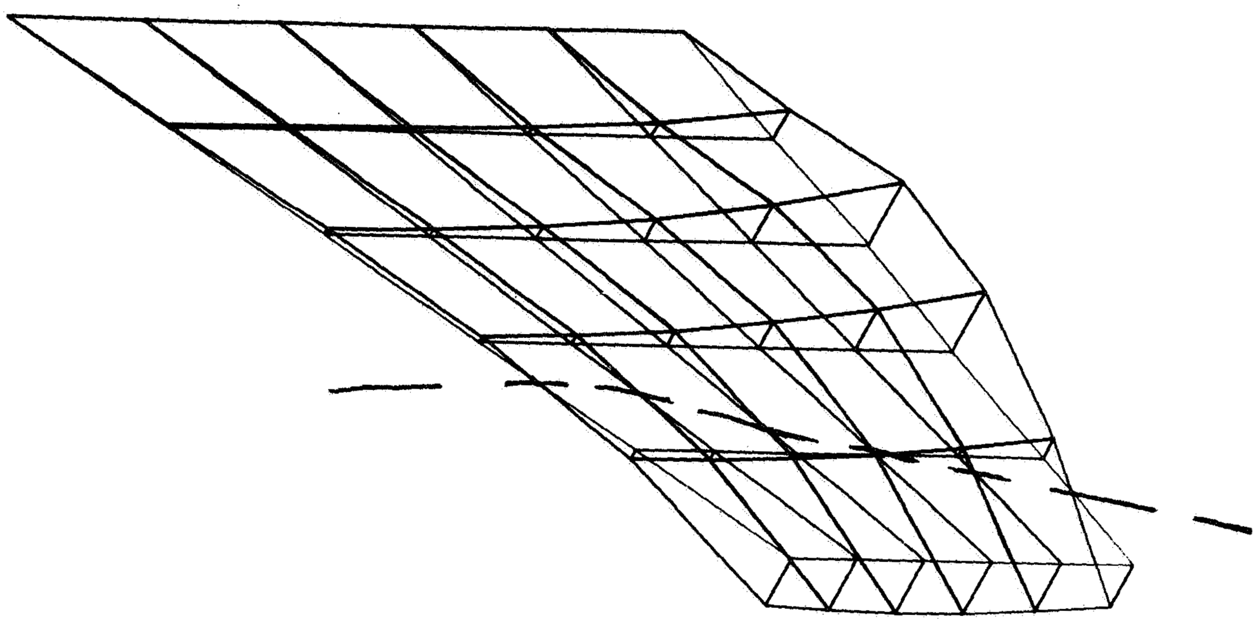


Mode 1; f_1 = 24.6 Hz

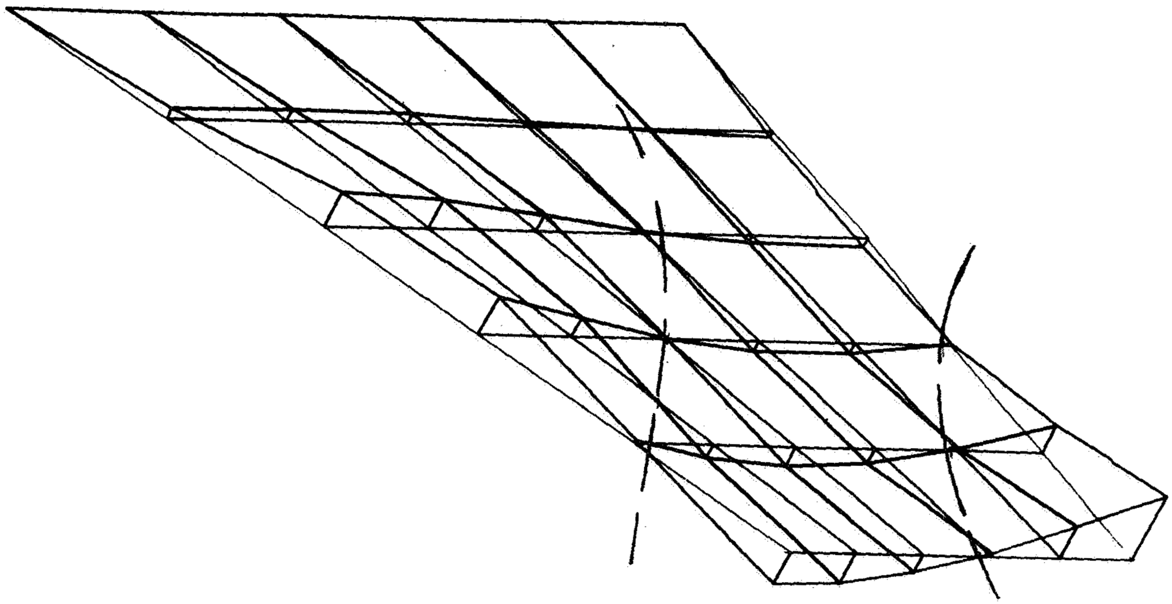


Mode 2; f_2 = 78.8 Hz

Figure 6.- Anisotropic cantilevered plate modes.

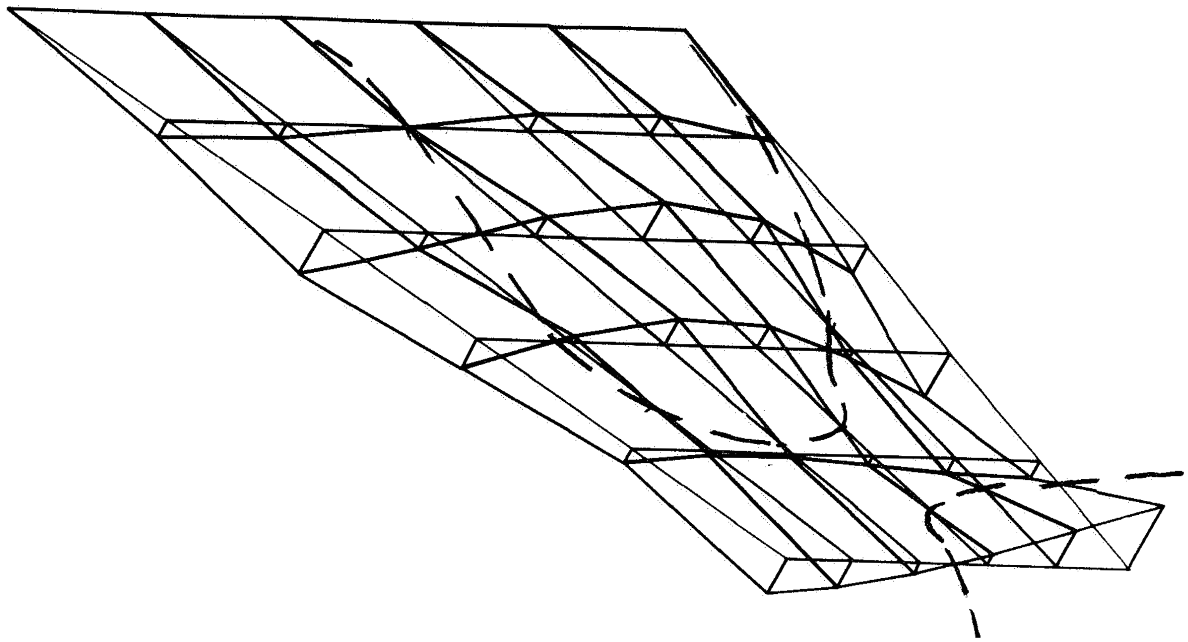


Mode 3; f_3 = 150 Hz

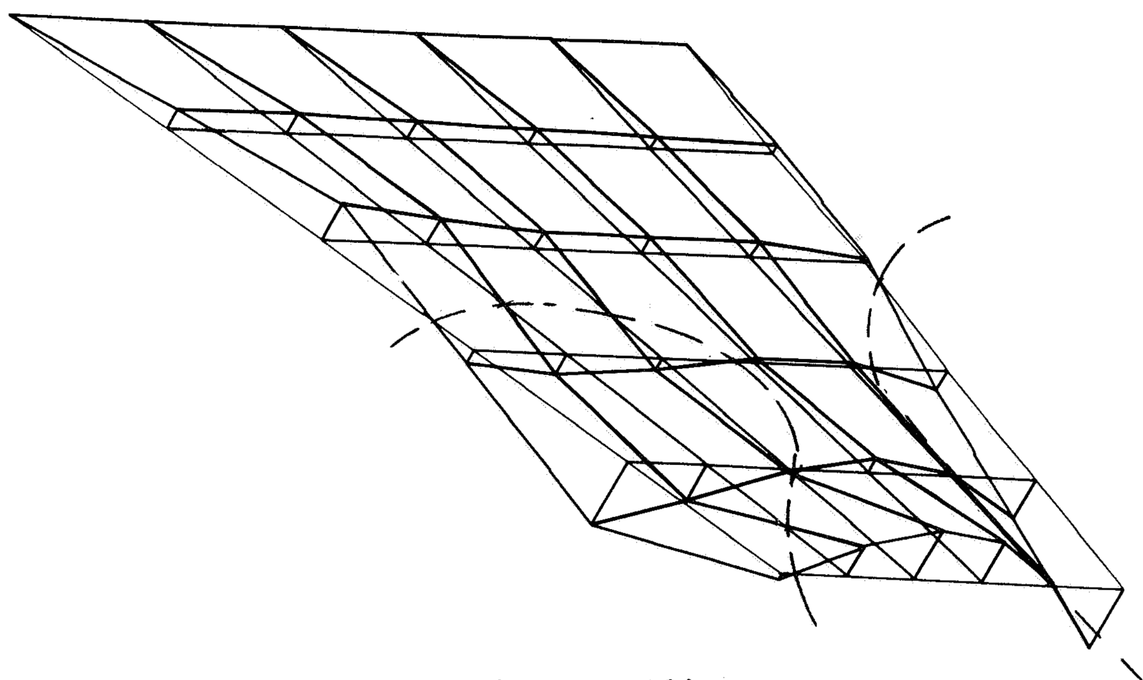


Mode 4; f_4 = 200 Hz

Figure 6.- Anisotropic cantilevered plate modes - Continued.

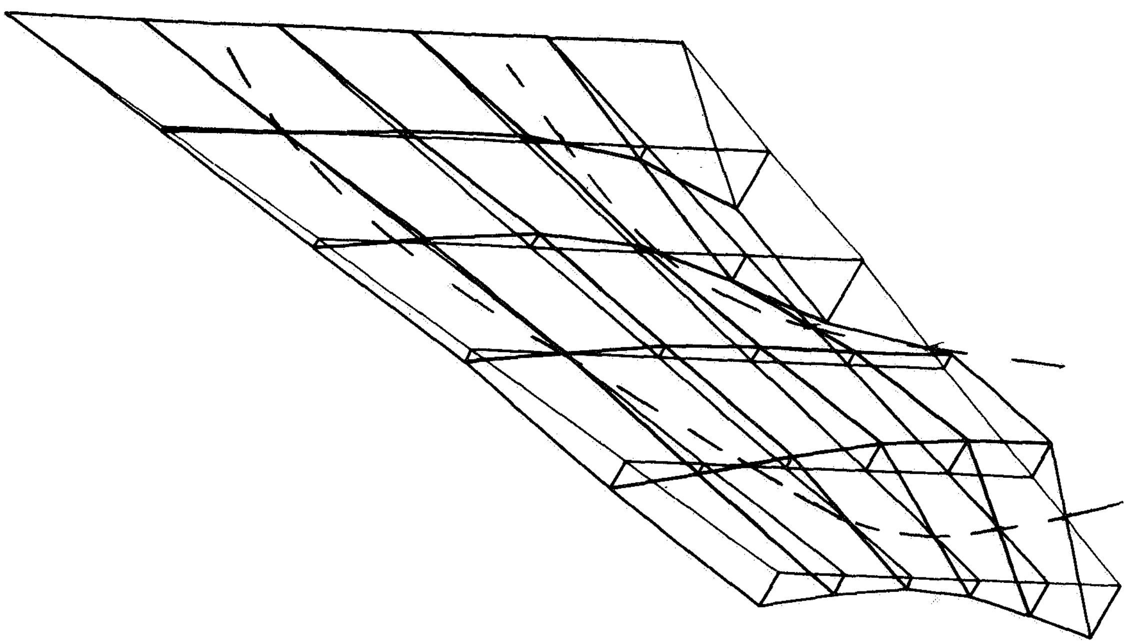


Mode 5; f_5 = 327 Hz



Mode 6; f_6 = 384 Hz

Figure 6.- Anisotropic cantilevered plate modes - Continued.



Mode 7; f_7 = 455 Hz

Figure 6.- Anisotropic cantilevered plate modes - Concluded.